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Radom Mitigation in 10 Clinton, New Jersey Houses A Case History

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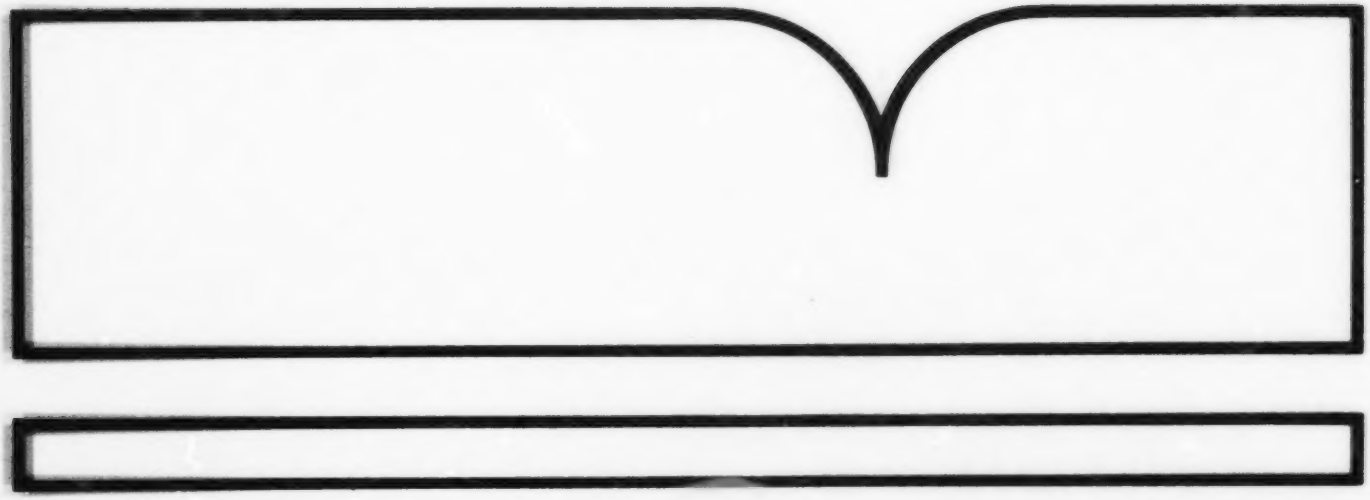

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RADON MITIGATION IN 10 CLINTON, NEW JERSEY, HOUSES: A CASE HISTORY

by

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16. ABSTRACT The paper discusses an EPA radon mitigation demonstration project in Clinton, NJ, which included testing radon reduction techniques in 10 houses. The 10 houses were selected from a group of 56 volunteers in the Clinton Knolls subdivision. Each of the 10 selected houses received an intensive radon diagnostic evaluation before a house-specific radon reduction plan was developed. Before and after the plans were implemented, radon concentrations were determined by charcoal canisters and continuous radon monitors. A variety of sealing and sub-slab depressurization techniques were applied to the 10 houses. Radon concentrations were reduced by over 95% in all 10 houses. Three-month alpha track radon measurements will continue in the radon reduction demonstration houses for the next 2 years.

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The U.S. EPA conducted a radon mitigation demonstration project in Clinton, New Jersey, which included testing radon reduction techniques in 10 houses. The 10 houses were selected from a group of 56 volunteers in the Clinton Knolls subdivision. Each of the 10 selected houses received an intensive radon diagnostic evaluation before a house-specific radon reduction plan was developed. Before and after the plans were implemented, radon concentrations were determined by charcoal canisters and continuous radon monitors. A variety of sealing and sub-slab depressurization techniques were applied to the 10 houses. Radon concentrations were reduced by over 95% in all 10 houses. Three-month alpha track radon measurements will continue in the radon reduction demonstration houses for the next 2 years.

Introduction

In March 1986 a resident of Clinton, New Jersey, reported very high radon levels in his house to the New Jersey Department of Environmental Protection (NJDEP). The NJDEP requested the assistance of the Environmental Protection Agency (EPA) through its radon mitigation research program. Within 24 hours EPA's Air and Energy Engineering Research Laboratory (AEERL) personnel were in the house in Clinton where radon had been discovered. They were making measurements, diagnosing potential radon entry routes, and developing a radon reduction strategy for the house. Because the radon concentrations observed in this house far exceeded any residential radon measurements previously made in New Jersey, the NJDEP conducted a general radon survey involving all interested Clinton homeowners. Charcoal canisters were distributed to the homeowners: the radon concentrations that were measured in 103 houses are summarized in Table I. Due to the alarmingly high radon concentrations observed in many of the Clinton houses, the NJDEP requested EPA's assistance in developing methods to reduce concentratons in the houses.

In April 1986, AEERL conducted screening visits in 56 houses in Clinton with the intent of selecting 10 houses where radon reduction techniques could be demonstrated. Evaluation criteria used in selecting the 10 houses included in the radon reduction project were: (1) the ability to identify and access the radon source in the house; (2) the ability to reduce radon concentrations with few potential complicating sources (e.g., fireplaces/chimneys); (3) elevated radon concentrations; (4) house sub-structures; (5) homeowner cooperation; (6) worker access to the house; (7) smokers in the house; (8) young children in the house; and (9) the time occupants spend in the house. Table II shows the distribution by floorplan of the houses selected for the demonstration study. All of these houses had radon concentrations in excess of 200 pCi/l in the NJDEP screening, and four of the houses had concentrations in excess of 1000 pCi/l.

Diagnostic Procedures

To provide maximum protection to the homeowners whose houses had been selected and to workers in the houses, all of the houses were opened to the maximum extent possible, and fans were used in the houses to produce good ventilation. This was possible due to spring and summer outdoor temperatures which caused minimum discomfort to the homeowner. Each of the 10 houses received a detailed radon diagnostic evaluation before a house-specific radon reduction plan was developed.

At the time work was initiated on the houses in Clinton, only a small amount of experimental data was availabe to assist in selecting techniques for assessing suitable radon reduction methods in houses. The EPA guidance document, "Radon Reduction Methods: A Homeowner's Guide"[1] and publications[2-7] describing similar radon reduction efforts provided a basis for the development of diagnostic and radon reduction approaches. Diagnostic techniques focused on the detection and isolation of three main mechanisms of radon entry and transport in a structure:

- Simple transfer through sub-structure openings. Radon enters into a house through openings connecting the house sub-structure to the soil. These entrance ways need not be very large to constitute a significant radon pathway. Small slab-cracks, pipes, sump holes, or any other features that penetrate the foundation of the house are likely sources.

- Negative-pressure-driven transport. Negative air pressure over the portion of the structure with soil contact results in a pressure-driven transport of radon and other soil gases into the house. Negative pressure can be induced by the use of fans, appliances, and natural ventilation in the house.

- Thermally driven transport. Differences in temperature between the soil-contacting portions of the building and the rest of the structure due to normal heating of the house may give rise to the thermally driven transport of radon from the soil into the house.

Although numerous sources have confirmed these general mechanisms, little information is available on their effect on indoor radon levels as the three mechanisms interact with one another in a house, nor are there data describing the interactive effects of other factors such as the tightness of a house or the operation of an assortment of common indoor venting devices such as a whole house fan.

Consequently, radon problems of the 10 houses in Clinton were diagnosed using two approaches. The first approach was to identify and characterize all possible sources of in-leakage, negative pressure, and thermally induced transport in each house. The second approach was to simulate, in isolation, conditions that might enhance or reduce radon transport and then measure the actual effect. The second approach was used in a few houses. Experiments in this second category included:

- Measuring the effect of whole house fan operation

- Investigating the negative pressure induced on the basement by the use of various household appliances

- Using a high volume fan to simulate winter-time stack effect

- Measuring the effect that furnace operation has on basement pressure

- Experimenting with supplied outdoor makeup air to reduce negative pressure.

In all cases, the objective of the diagnostic procedure was to understand the mechanism and identify sources of radon infiltration to develop a low-cost and effective radon reduction strategy for each demonstration house.

Qualitative Measurements of Soil Gas Entry

In all cases, extensive visual examinations were made of the floors, joints, and undergrade walls of each house to identify potential entry points. A simple smoke tube test was made at any potential site of entry to determine the direction of air flow. If the smoke was blown back into the room the opening was considered to be a possible point of radon entry. Although this test does not determine the radon content of the incoming air stream, it does locate potential influx sites. Because factors such as windspeed and direction greatly affect smoke tube results, outdoor and indoor conditions were noted and pressure difference measurements were made wherever possible.

Characterization of Sub-slab Aggregate

Because of the high radon concentrations encountered in the 10 demonstration houses, it seemed likely that soil depressurization techniques would be necessary. Consequently, all houses were inspected in an attempt to determine the composition of the sub-slab aggregate.

The sub-slab material was inspected visually by drilling holes in the slab with a hammer drill. Light from a flashlight through a 1-in. (2.5 cm) diameter hole was frequently sufficient to view the sub-slab material.

When a visual inspection of the sub-slab was impossible or uninformative, several indirect methods were used to determine if the material was porous enough to allow effective soil depressurization. With a hole drilled through the slab and negative pressure applied to the basement using a fan or some other technique, a smoke tube over the hole was used as a visual inspection technique. If the smoke was forced out of the hole, sub-slab entry of soil gases was suspected. To determine the sub-slab characteristics, a second slab hole was drilled. At one hole, a vacuum cleaner was sealed over the hole to apply suction on the sub-slab material. At the other hole, a smoke tube was used to determine the effect of suction through the aggregate. More quantitative results were achieved with the substitution of an inclined manometer for the smoke tube to actually measure the pressure gradient through the sub-slab material.

A more elaborate method of assessing sub-slab material was developed using freon gas [standard 15-lb (6.8 kg) cylinder] as a tracer and a halogen detector (TIF model 5500: TIF, 9109 N.W. 7th Ave., Miami, FL 38150) to follow the freon transfer into the building. Freon is injected through a hole in the sub-slab, and the detector is used as a sniffer to locate relative changes in freon concentrations in the building. A low concentration of the gas is sufficient, and the lowest detectable concentration should be used at all times. This technique was particularly useful in detecting problems in already installed radon reduction systems.

Measurement of House "Tightness"

House tightness is used, in the context of this paper, to indicate qualitatively the leakage area in a house. Air exchange rate measurements were made on each of the 10 houses in Clinton using a standard blower door test (ASTM Method E3779-81). One purpose of these measurements was to determine if high indoor radon levels in the Clinton houses could be attributed to the tightness of the structures. If tightness showed a good correlation with high radon levels, radon reduction measures might concentrate on compensating for the low volume of available dilution air in a house. Figure 1 is a plot of the estimated air exchange rates in the 10 houses using the results of the Lawrence Berkeley Laboratories model[8] versus the NJDEP screening study charcoal canister radon concentration results for each house. A curve that represents the best fit to the data is superimposed on the figure.

On the basis of these results, it was concluded that the extremely high radon concentrations encountered in the Clinton houses were not due to tightness of the structures, but were more likely due to the unusually high source strength. For dilution ventilation alone to provide a sufficient reduction in radon concentrations, the airflow through these houses would have to be increased from approximately 200 cfm (5.7 m^3/min) to a rate of

25,000 cfm (710 m^3/min). The cost and discomfort presented by this option indicated that radon reduction methods that concentrated on lowering the entry rate of gas to the houses would be more effective and practical.

Simulation of Winter Conditions

Data from a variety of sources have confirmed that wintertime indoor air concentrations of radon are higher than even those taken under closed house conditions in other seasons. It has been speculated that elevated winter concentrations may result from:

- The formation of a nearly impermeable cap of either frost in the upper soil or a layer of melting snow that inhibits diffusion of radon into the air from the ground surface and results in high concentrations of radon in the soil gas.

- Combustion heating equipment and a temperature-induced stack effect in a house that produces a negative pressure on the basement. Makeup air for this suction is drawn into the house from outside above grade, but some fraction of it is drawn through cracks and holes in the below-grade foundation.

Pre-radon reduction continous monitor radon measurements were made in the 10 houses in the early to late summer. Post-radon reduction continuous monitor measurements were made in the early to late fall. Because these measurements spanned a variety of weather conditions but never winter conditions, an attempt was made to simulate winter conditions during some of the pre-radon reduction monitoring. It was not possible to induce ground-freezing conditions; however, it was possible to simulate basement depressurization and a temperature-induced stack effect.

A 20-in. (51 cm) diameter three-speed window fan was placed in a living-space window while radon was monitored continously using a Pylon AB-5 and passive scintillation cell. For one-third of the monitoring period, the house was closed with the fan off; during the second third of the sampling period, conditions were identical except the fan was on; and during the third part, windows were opened but the fan was off. Detailed results from this experiment are reported by Brennan and Osborne[9].

The results of that study indicate that a fan-induced negative pressure on a house has a distinct impact on the radon concentrations in that house. In some houses, the technique appears to adequately simulate wintertime entry rates even in the summer, while in others there is little to distinguish a house monitored under simulated winter conditions from the same house monitored under closed house conditions. Winter conditions cannot be uniformly simulated during the summer since the ground is not capped with snow or frost. A fan induces a negative pressure over the entire building shell, whereas in typical winter conditions the basement is under the highest negative pressure and the top of the house is under positive pressure due to the buoyancy of the warmed air that is driving the stack effect.

Simulation of thermally driven effects was also attempted. The temperature in one of the houses was raised to induce stack effect negative pressures by running the furnace simulating combustion appliance draft. A fan will bring in approximately twice as much dilution air as the temperature driven stack effect for the same negative pressure put on the basement. Running the house warmer than the outside air will reduce the artificial introduction of dilution air. However, this method is

impractical for summer use because of discomfort and possible damage to temperature-sensitive plants, furniture, or musical instruments.

Increasing Makeup Air

Additional negative pressure in basement areas produced by the normal operation of furnaces can result in increased indoor radon levels. One approach to controlling this effect is the introduction of makeup air to the basement or the furnace itself. Several methods of providing makeup air were tested in house C30A. An 8 cfm (2.3 m^3/min) fan was used to push air down a chimney by-pass. This size fan had an almost imperceptible impact on the negative pressure between the basement and outside air.

A second effort involved blowing air directly into the basement with a fan mounted in a basement window. This method was marginally more successful and required the use of a fan which had to be switched on and off by the homeowner.

A third method used a 6-in. (15.2 cm) insulated duct to supply intake air to the return air plenum of the furnace distribution system. When the furnace blower was running, about 100 cfm (2.8 m^3/min) of outside air was introduced into the 1,200 cfm (33.6 m^3/min) flow in the plenum. The simplicity and passive nature of this technique make it recommendable over the use of active methods of supplying makeup air. Active introduction of outside air into a house may produce excessive basement cooling when operated in the winter; consequently, the passive technique was adopted for use in the 10 houses when the reduction of negative pressure using dilution air was required.

Radon Reduction Plans

Radon reduction plans were developed for each of the 10 houses based on their prior diagnostic assessments, discussions with the homeowners and construction contractor, and available information about effective radon reduction techniques.

Summary radon reduction plans were prepared for discussion with the homeowners and construction contractor to describe the installation that would be necessary. Homeowner involvement in the selection, development, and implementation of the plan was encouraged. A homeowner permission form was discussed with each homeowner and was signed by the homeowner before proceeding with the installation.

Table III summarizes the important construction features and the general radon reduction options selected for each of the 10 houses.

The four split-level houses that were included in the study were each a combination of block wall basement and slab-on-grade sub-structures with a common wall. The slab-on-grade section of these houses had forced warm air heating ducts beneath the slab. These ducts were not tightly sealed at the joints, and some of the ducts had clearly settled in the soil leaving a large gap between the register and the duct. A smoke pencil easily demonstrated the potential entry of soil gases from around the outside of the ducts and into the house via the heating registers.

The major solution to the radon problem for the slab-on-grade portion of the split-level houses was to seal the slab just below the

registers with concrete and reroute new heating ducts into the attic. A plastic pipe with an in-line fan was then connected to the abandoned heating ducts, creating suction in the ducts and surrounding sub-slab area. In addition, two of the four split-level houses also had their floor/wall perimeter cracks sealed.

The basements of these houses were found to have several inches of crushed stone beneath the slab and both interior and exterior, below slab drain tiles. Sub-slab suction was applied by inserting plastic pipe with in-line fans through openings created in the concrete slab in two houses and through existing sump holes which were later sealed in the other two houses. All of these sub-slab systems were vented to the outside through the roof. Major accessible cracks and penetrations in the floors and walls were also sealed.

The three bi-level houses, often referred to as split foyers or raised ranches, had completely finished living space on the lower level. The slab floor on the lower level was typically from 0 to 3 ft (0-91 cm) below grade. Two different approaches were tried for the three houses. In the first house, sub-slab suction was attempted with little success due to the lack of sufficient aggregate beneath the slab. As a second phase of radon reduction, the floor/wall perimeter crack was enlarged and a backer rod spacer placed in the crack before a tight polyurethane seal was used to cover the crack. This also left a channel beneath the backer rod around the perimeter of the house which was connected to a plastic pipe with an in-line fan. This technique permitted perimeter suction of the floor/wall crack which was exhausted through the roof.

The other two bi-level houses were subjected to a different radon reduction approach because of the difficult job encountered in the first bi-level when trying to enlarge the floor/wall crack. These two houses had their floor/wall cracks sealed, but the primary radon reduction technique was applied from the exterior of the houses. Along one side of the two houses, a trench was dug to the level of the first hollow core foundation block. Three different penetrations were made in blocks along this wall. Two penetrations, made at the corners of the side wall, entered the void space in the foundation blocks on the front and rear walls. These penetrations permitted block-wall suction on the front, side, and rear walls. In the center of the side wall, a penetration was made through the block and into the loose backfill soil near the floor/wall crack beneath the house floor slab. By tying all three penetrations along the side wall into a common vertical plastic vent pipe equipped with an in-line fan, suction could be applied simultaneously to three walls and the sub-slab.

The two-story basement house had a much larger basement space than the split-level houses, requiring two sub-slab suction points at opposite ends of the basement. The two suction systems were not ducted together; each had its own fan. The cracks and floor and wall penetrations were sealed.

The two-story slab-on-grade house was the house in Clinton where radon was first discovered. This house presented a special problem because it had sub-slab heating ducts similar to the slab portion of the split-level houses. Unfortunately, since the house was two-story, new heating ducts had to be routed through the available space between floor joists in the ceiling of the first floor. This was both difficult and expensive since it required resurfacing some of the walls and ceiling.

Again, the original heating ducts were used for sub-slab suction, similar to the split-level houses. In addition, due to the high radon levels in this house, a perimeter floor crack suction system (similar to the first bi-level house) was used.

A different type of split-level house built by another contractor was the tenth house to receive radon reduction treatment. This house was a combination of slab-on-grade and crawl space with a common wall. The slab-on-grade portion of the house received an interior (crawl space) below-grade suction technique similar to the exterior technique used on the last two bi-level houses; however, only one penetration point was used, to apply suction to one side wall and the rear wall.

The open soil in the crawl space of this house was covered by a fiber mat. On top of the mat, a network of perforated PVC pipe was completely covered by 10 mil polyethelene plastic. The plastic was held in place and sealed at the edges by wooden furring strips. The PVC pipe was connected to an in-line fan and vented to the outside.

Results

Before and after the radon reduction plans were implemented, radon concentrations were determined by charcoal canisters and continuous radon monitors. The early charcoal canister data were obtained by the NJDEP before the warmer springtime weather reduced the cold weather stack effect. Unfortunately, the pre-radon reduction continuous monitor data were collected during warmer weather when radon concentrations were lower. Therefore, the pre- and post-radon reduction data reported in Table IV are only charcoal canister data. These are the only data available for this project which compare cold weather concentrations before and after radon reduction.

Conclusions

A combination of often-tried and novel radon reduction techniques have been successful in Clinton, New Jersey, in significantly reducing radon concentrations. Although several of the demonstration houses continue to show wintertime radon levels above the sought-after 4 pCi/l concentration, all 10 houses are clearly below the immediate action level of 200 pCi/l. The initial success achieved in the Clinton radon reduction demonstrations are being tested over the winter heating season when the driving forces are the greatest for radon entry into the houses.

An effort to identify additional radon reduction techniques which could be effective in further reducing the radon levels in the demonstration houses is currently underway. The long-term monitoring plan for the 10 homes requires obtaining 3 month alpha track measurements for the next 2 years. Analyses of the first quarter's data will soon be completed.

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TABLE I: CLINTON RADON LEVELS

Concentration pCi/l	No. of Houses	% of Sample
>2048	2	1.9
1024-2047	3	2.9
512-1023	13	12.6
256-511	17	16.5
128-255	17	16.5
64-127	12	11.7
32-63	12	11.7
16-31	14	13.6
8-15	5	4.9
4-7	6	5.8
<4	2	1.9
	103	

TABLE II: DISTRIBUTION OF HOUSES SELECTED FOR DEMONSTRATION

Construction Design (sub-structure)	House No.
Split Level (combination slab-on-grade and block basement)	C8A C30A C39A C46A
Bi-level (slab-below-grade)	C10B C31B C48B
2-Story (slab-on-grade) (block basement and crawl space)	C33C C32D
Other (split level with combination slab-on-grade and dirt crawl space)	C24E

TABLE III: SUMMARY OF RADON REDUCTION METHODS APPLIED

Radon Reduction Method	House No.
Sump hole suction (includes drain tiles and sub-slab)	C39A, C30A, C32D
Sub-slab suction (interior)	C48B, C46A, C8A, C32D, C24E
Sub-slab suction (exterior)	C10B, C31B
Rerouting, sealing, and applying suction to sub-slab ducts	C30A, C39A, C46A, C8A
Perimeter crack suction	C48B, C33C
Seal perimeter crack (no suction on crack)	C31B, C10B, C39A, C46A
Supply makeup air to furnace (dilution)	C48B, C30A, C46A, C39A, C33C
Ventilating and isolating crawl space	C24E

TABLE IV: CLINTON RADON REDUCTION RESULTS

House No.	Concentration, pCi/l 3/86-4/86	11/86-1/87	Reduction, %	House Type
C30A	2254	4	99.8	
C39A	1523	4	99.7	= split level
C46A	635	9	98.6	(block basement/slab)
C8A	791	3	99.6	
C31B	691	6	99.1	= bi-level (slab partly
C48B	963	11	98.9	below grade)
C10B	418	16	96.2	
C33C	1190	5	99.6	= 2 story (slab)
C32D	1357	11	99.2	= 2 story (block basement +crawl)
C24E	426	12	97.2	= 2 split level (crawl space /slab)

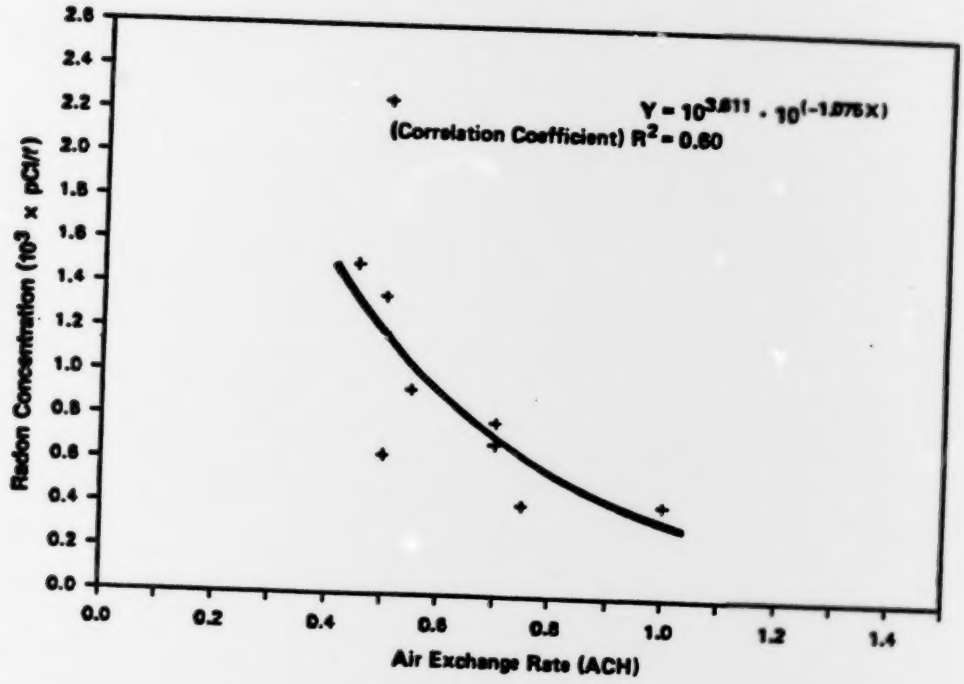

FIGURE 1. RADON CONCENTRATIONS VERSUS AIR EXCHANGE RATES, CLINTON HOMES.